Flood triggered oil spills: Lessons from the Natech accident in Saga prefecture in August 2019.

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Synopsis

With the aim of extracting lessons learned, this study investigated a large oil spill at an ironworks factory in Saga prefecture, during the severe flooding that hit southwestern Japan in late August 2019. The oil spill dispersed by the flood waters contaminated adjacent crops, irrigation canals and citizens' homes in a large area of Omachi town. Many citizens had practiced vertical evacuation. Due to the oil spill, the pumping of flood waters had to be stopped to prevent further contamination, resulting in oil stagnating in the area for several days. This meant that residents had to be rescued from their homes in the middle of strong oil vapours. The oil spil's possible long-lasting impact in terms of health and environmental pollution requires monitoring and further investigation. The study found that oil spills caused by floods had already occurred at the same site, highlighting the need to improve risk management of chemical hazards, develop flood risk maps that consider the potential for these types of secondary events and other compound disasters, and propose more effective strategies for emergency planning and response.

1. Introduction

This study investigates an oil spill from an Ironworks factory in Saga Prefecture, Japan, triggered by severe flooding in late August 2019. The importance of the study lies in the fact that there is still relatively little work published concerning case studies of flood related technological accidents and their overall impacts.

This study contributes to the body of knowledge on technological accidents triggered by natural hazards (known as Natechs; see Showalter and Myers 1994; Krausmann *et al*. 2017) by elucidating the causes, direct and indirect consequences, and environmental impacts of the flood triggered oil spill.

Furthermore, the study analyses the emergency response and clean-up activities to identify lessons learned, and propose recommendations to prevent, prepare for, respond and recover from future flood related Natech events.

According to a study by Sengul *et al.* (2012), where the authors analyzed chemical accidents reported to the National Response Center database in the United States in the period 1990-2008, hydrometeorological related accidents represented over 70% of all identified Natech events (26% rain induced, 20% hurricane induced, and 25% attributable to storms, winds, and other unspecified types of weather). Another study identified Natechs in the French chemical accident database called Analysis, Research and Information on Accidents

(ARIA) [1], finding that flood and storm related Natechs represented about 46% of reported Natech accidents in the database between 1992 and 2012 (French Ministry of Ecology and Sustainable Development, 2013).

Due to climate change, it is expected that some regions may experience stronger heavy rainfall events, as well as stronger tropical storms both of which can result in flooding. Thus, identifying lessons learned from past flood related Natechs is crucial for improved risk management, particularly in view of the possibility of more frequent severe floods due to a changing climate.

The heavy precipitation that hit southern Japan in late August 2019, caused unprecedented downpours and massive flooding over vast areas. Saga Prefecture, in Kyushu Island, was particularly affected and authorities registered precipitation levels about double the normal level for the time [2]. Thousands people were instructed to evacuate, main train stations were flooded and two people died [2–4]. Extreme rainfall events of this kind are likely to flourish both in terms of frequency and severity in the future. Indeed, the number of climate and weather-related disasters are growing in many areas worldwide along with their costs (NOAA, 2019; Natcat Munich Re, 2019). According to the recent World Economic Forum, extreme weather events and climate change became priority risks for the economy at the global level (World Economic Forum, 2020). Considering the case of Japan, the overall losses due to weather and hydrological disasters from 1980 to 2018 have been estimated at 129 billion US$ (Natcat Munich Re, 2019). Moreover, according to IPCC, the risk related to extreme weather events is going to further increase in the foreseeable future due to climate change (IPCC, 2018). Recent research pointed out that the intensity of severe precipitations may increase in Japan as a consequence of the changing atmosphere air temperature during the current century [9][Nayak et al., 2018]. In addition to extreme rainfall events, previous research highlighted statistically significant increases in severe tropical cyclones (i.e., categories 3 and 4 on the Saffir-Simpson scale (Saffir, 1973; Schott *et al*., 2012; Ruckart *et al*., 2007; Misuri *et al.*, 2019) hitting southern Japan (Yoshida *et al.*, 2017).

It is not surprising then, that the oil spill investigated in this study is not a one-time event. In fact, as this study found, oil spills at the same Ironworks plant had occurred in the past, and structural mitigation measures had been adopted. The event in August 2019 exceeded the design level of the protection measures, which may indicate that more needs to be done to be better prepared for these types of compound disasters in consideration of changing climate patterns. This study hopes to provide some insights and recommendations based on lessons learned from the accident.

2. Natechs caused by weather related hazards

Heavy rainfall, flooding and other hydrometeorological hazards may constitute potential triggers for hazardous material releases. The oil spill of August 28, 2019 in Saga prefecture is an example of a Natech event. Natechs represent about 3% of all reported chemical accidents in databases in the United States and Europe (Sengul *et al.*, 2012; Xiaolong and Cruz 2020). More than a fourth out of the totality of of all hazardous material releases triggered by natural hazard events in the United States were caused by rain between 1990 and 2008 (Sengul *et al*., 2012). Between 2000 and 2001, about 44% of chemical releases related to adverse weather conditions in United States (including weather disasters as hurricanes) was caused by rainfall (Ruckart *et al.,* 2004].

Japan has suffered Natechs caused by hydrometeorological hazards in the past. The explosion caused by flooding brought by heavy downpours in an aluminium factory in Soja city Okayama Prefecture, in July 2018 serves as a recent example (Araki *et al.*, 2020].

In this paper we investigate the oil spill caused by flooding in Omachi town, Saga Prefecture. The results are presented in the following sections.

3. Description of the event

Omachi town, the area of the accident, is mainly constituted by reclaimed land from the Ariake Sea; its geological history is clearly linked to the high flood proneness of the whole Saga plain. In the next section a brief historical background of the area together with a historical perspective on the recurrent past flooding events will be given, which should help the reader to understand the flood hazard the population is exposed to.

3.1 Historical background

Saga Prefecture mainly lies over a low flatland area. As can be seen from Figure 1, the actual coastline on the Ariake Sea is the result of centuries of soil reclamation activities which began around the 6th century (MLIT, 2011). The Saga plain is deeply characterized by the presence of the Rokkaku and Ushizu rivers, the two main fluvial systems of the

[1] ARIA (Analysis, Research and Information on Accidents) database compiles data on chemical accidents and near miss events. ARIA is kept by the French Bureau for Analysis of Industrial Risks and Pollution.

region, whose basin area is of about 341 km^2 (MLIT, 2011). About 60% of the river basin is an inland water area, and the elevation of the plain is mostly between 0-3m ASL (MLIT, 2011). The river system is thus difficult to manage.

Indeed, the Ariake Sea tidal range reaches up to 6m, and in case of high tide, seawater flows upstream and may reach up to 29 km inland on the Rokkaku river (MLIT, 2011]. It is not surprising thus that previous major floods that hit the region brought massive destruction.

To find more information on flood proneness of the region a historical research in the Japan Times (Japan Times 2020) archives was carried out.

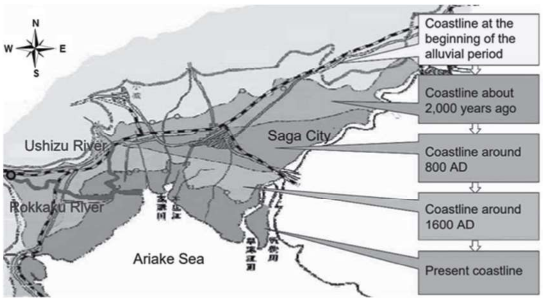

Figure 1. Coastline of the Saga low flatland area. The source of oil spill is indicated in red. Adapted from MLIT.

Twenty floods were identified which hit the capital of the region in the period of 1900-2009. The three most severe floods occurred in 1923, 1953 and 1990. The information retrieved gives also clear indications on the high frequency of floods affecting the region. Indeed, the set of floods identified corresponds to an average return period of 5.45 years (frequency of 1.83e-01/year) in the analyzed timespan. It should also be noted that an acceleration is highlighted between 1950 and 2009, with 14 floods reported (average return period of 4.2 years), compared to the previous 50 years (6 floods with an average return period of 8.3 years). This higher frequency might be explained considering possible underreporting in the past, but might also be an indication of climate change effects on the area.

Despite the research on Japan Times is restricted to the capital city, other sources confirmed that these events had a massive impact in the entire region. Indeed, during the floods of June 1953, more than 14,000 houses in the prefecture were flooded and many landslides were triggered due to soil failure (MLIT 2019). Again, heavy rain in August 1980 caused high waters to collapse river embankments and about 1700 houses were flooded (MLIT 2019). During a heavy rainfall event in July 1990, river embankments broke in 10 locations, leading to catastrophic flooding. Floodwater covered about 8000 ha of farmland and submerged the foundations of more than 5500 houses [38][MLIT 2019]. Another flooding event impacted the region in July 2009 (MLIT, 2019). Structural countermeasure against flooding were constructed and maintained such as embankments, dams, and retarding ponds. Furthermore, drainage pumps have been installed in the area to allow water discharge into the rivers (MLIT, 2011). Nevertheless, these measures have not been effective in case of extreme rainfall events. In the July 2018 rainfall event, which again led to widespread flooding, the river and pumping systems were so overburdened that embankments broke also in one area upstream on the Rokkaku river for the first time after 1990 (MLIT, 2019).

The town of Omachi, where the oil spill happened, is located along Rokkaku river's main channel. As it is highlighted in government flood hazard maps for the river system reported in Figure 2, the southern part of the municipality is exposed to flood hazard (MLIT, 2016). The map was created considering the worst-case scenario of inundation caused by the Rokkaku river water system. The rainfall scenario considered is of 424mm in 6-hour period (MLIT, 2016). As can be seen, the water height may reach up to 5m. The worst-case scenario approach is included in flood control evaluations since 2015, and the maximum rainfall scenario to be considered in simulations depends on the region in Japan considered and on the extent of the catching area of the river system (MLIT, 2015). It should be noted that the return period for this scenario is not provided, although in case the estimate results in a significantly lower rainfall severity compared to a 0.1% exceedance probability scenario, the severity of the latter is suggested to be assumed. Therefore, the flood hazard map reported in Figure 2 can be conservatively associated to a 1000-year return period (MLIT, 2015).

3.2 The floods of August 2019

From August 27th 2019, a rain front caused strong rainfall over a wide area of the Japanese island of Kyushu. In the morning of August 28th, a special rain warning was issued by the Japan Meteorological Agency (JMA) in Saga, Fukuoka and Nagasaki prefectures (JMA, 2019). The warning required immediate evacuation to designated sites in case it was possible, while in case this was not possible, citizens were instructed to move to highest floors of the closest solidly built buildings, away from cliffs and rivers, and in case neither this was feasible, they were required to promptly perform vertical evacuation for imminent catastrophe reaching highest floors of their houses (JMA, 2019). Consequently, an emergency evacuation order was issued by Fire Disaster Management Agency (FDMA) to more than 850,000 people in the three prefectures (Mainichi, 2019; Floodlist, 2019).

In Saga prefecture, observed rainfall levels exceeded the levels registered during the major flood of 1990 (MLIT, 2019) and caused a critical water inflow to the Rokkaku river water system. Indeed, the peak level of the Rokkaku river reached 4.12m on August 28th, surpassing the level of 3.1m height indicating potential imminent flooding (MLIT, 2019-3). The Ushizu river, belonging to the same water system, surpassed 7.02m the same day, while the established flood danger level is 4.4m (MLIT, 2019). The latter river in particular experienced an unprecedented peak level even higher than the one reached in 1990 of 6.04m (MLIT, 2019). The unprecedented downpour thus led to the collapse of the Rokkaku river water system causing breaches from nine different locations and large-scale flooding involving more than 6900 ha of land and 2936 house units (MLIT, 2019).

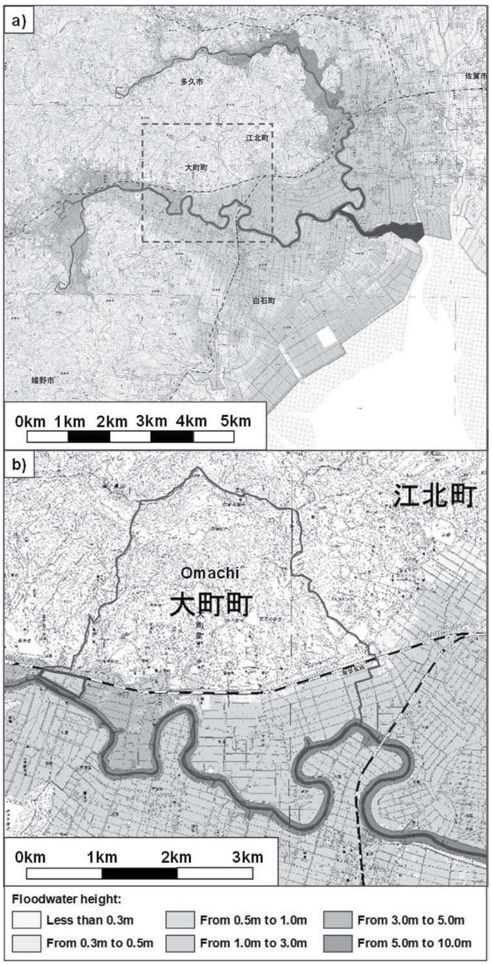

Figure 2. a) Flood hazard map for the Rokkaku river water system; red dashed line indicates Omachi town area reported in b). b) Detail of flood hazard map for Omachi town area; blue line indicates the position of ironworks factory. Floodwater height is estimated considering the worst-case rainfall scenario of 424mm (6-hour period) (MLIT, 2016).

The main transportation infrastructures were disrupted, landslides were triggered in many locations, many road connections were submerged, and train connections with the region were partially suspended due to flooding of principal stations (Mainichi, 2019, Japan Times, 2019).

3.3 Oil spill at the ironworks factory

The factory involved in the oil spill accident is an ironworks plant specialized in production of high-strength bolts for automotive and agricultural applications (Nishinippon Shimbun, 2019). The manufacturing site is located less than 100m from the Rokkaku river embankment. The site has been running since 1969 and occupies a surface of about 99000m^2, while buildings occupy about 41000m^2 (Saga Tekkosho, 2019). The factory operates in continuous mode (i.e., 24h/ day). Some of the key steps for obtaining high performance bolts involve the use of heat treatments for hardening the surface in the final stages of the manufacturing process (Totten et al., 1993; MacKenzie, 2009). According to the available information, the plant performs a quenching operation in an oil bath kept in atmospheric storage tanks located 3m below ground level for safety matters, before the tempering treatment (Saga Shimbun, 2019). Quenching is one of the typical processes performed in metalworks to obtain specific mechanical characteristics and consists of the rapid cooling of heated pieces through large volumes of oil, water, or air (Totten *et al.*, 1993; Totten *et al*., 2003; Abbaschain *et al*., 2009). One of the typical equipment design solutions for heat treatment of small parts as bolts is a furnace which is directly connected to quench tanks located below the conveyor level that the parts reach directly through a chute (Totten, 2007; Edenhofer *et al.*, 2015).

According to a report in the Saga Shimbun, inside the thermal treatment building of the plant there were eight oil tanks with an overall capacity of more than 100,000 l of oil. Since the bolt production is carried out in a continuous regime, the quench tanks are not equipped with lids. Thus, it is difficult to seal them (Saga Shimbun, 2019).

The plant was flooded around 04:00AM on August 28 (Tellerreport, 2019). The protection measures in place for flood prevention were not effective. At the time of the accident, seven night shift workers were in the plant, and managed to stop operations around 04:30AM (Saga Shimbun, 2019; Tellerreport, 2019). A drainage pump was in place as a preventive measure, and there is contradictory information on whether the tanks were sandbagged or not (Nishinippon Shimbun, 2019; Tellerreport, 2019; Japan Times, 2019). Floodwater reached up to 60cm depth inside the plant, flowing into the tanks and lifting the stored oil (Saga Shimbun, 2019). Other sources report water inside the building reached 40cm, while outside it was about 70cm (Nishinippon Shimbun, 2019). According to the Saga Shimbun at 5:00AM the oil spill was confirmed by the workers that had to evacuate at 5:30AM due to the danger brought by the severe flooding and the oil spill. Around 6:30AM the oil outflowed from the premises of the factory (Saga Shimbun, 2019).

The quantity of released oil was not clear at the beginning, and during a preliminary field survey conducted by the authorities on September 3rd estimated that about 110,100 l of quenching oil and about 3000 l of metal working oil were released inside the factory due to the floodwaters [54]. In a later estimation, the company declared that out of 103,000 l which were stored in the quench tanks the day before the accident, 49000 l were released but kept into the premises of the factory, while the remaining 54000 l spilled outside the plant [55].

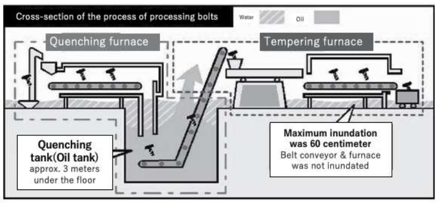

Figure 3. Simplified scheme explaining the dynamics of oil spill caused by flood. Adapted from (Saga shimbun. 2019).

The oil sheen spread to residential areas and over flooded agricultural fields, damaging dwellings and finally reaching the hospital that was isolated due to the flood. No patients or staff were injured, but they were stranded in the building due to oil-tainted floodwater (NHK, 2019).

Figure 4. Aerial view of the area impacted by the oil spill. Adapted from: https://usagi-syufulife.com/2019/08/31/2285.

It should be noted that the same ironworks factory was involved in an analogous oil spill during 1990 floods [56]. After that accident, the heat treatment building was retrofitted with heavy shutters, and the floor level was raised by tens of centimetres to reduce the risk of water entering the oil tanks in case of future flooding [47]. Apparently the 2019 flooding was a beyond-design-basis event, with an unforeseen intensity that made all the safety measures ineffective.

3.4 Characteristics of the spilled oil

The oil employed in thermal treatment processes needs to satisfy a number of critical properties required by technical application at high temperature. Indeed, quench oil formulations need to have acceptably high flash point and low volatility, so as not to catch fire during operation, need to be stable to avoid sludge formation and must have appropriate thermophysical properties to guarantee an efficient heat removal [45][Totten et al., 1993]. The oil employed in the facility is produced by a major Japanese oil company [55][Saga Shimbun, 2019]. Considering the atmospheric quenching process employed to achieve high performance parts, and consulting Safety Datasheets (SDS) of main products from major sellers for this kind of treatments [57][SDS master], these substances are likely classified as “Category 1” chemicals for aspiration toxicity, and according to Globally Harmonized System (GHS) terminology for hazardous properties classification [58][GHS]. This means the oil potentially poses an immediate threat to the population residing in the impacted area. Beside the acute effects to human health related to this class of substances, some high-performance oils employed for thermal treatment and metal working are mixed with small percentages of additives to enhance their thermal stability and reduce sludge formation [46][MacKenzie, 2009]. Some of these additives are also classified as hazardous substances. For instance, this oil category may contain cresols in low percentage, according to the safety data sheets (SDS) of commercial products for atmospheric quenching process (SDS Bright 2015). These chemicals are associated with an H410 hazard statement (according to the Global Harmonized System (GHS) International Standard), meaning these compounds are “Very toxic to aquatic life with long-lasting effects” (United Nations, 2019). Other commercial solutions for metal working may contain additives considered neurotoxic and potentially toxic for reproduction (Indemisu Hermetic 2014). Typical hazardous properties of commercial oils employed in ironworks processes are reported in Table 1 below.

Given the hazardous properties of oils typically used for metal quenching, the long-term impact of the oil spill on the environment and public health should be monitored.

4. Post-disaster actions and damages

The water depth in the area where the oil spill occurred peaked at 3m in the aftermath of the accident (Tsukasa, 2019). In order to limit oil spreading and prevent it from reaching the Rokkaku river, five oil booms were set up from the morning of August 28 and personnel from the Self-Defense Forces (SDF) and town officials were dispatched in the area to collect the oil (Tellerreport, 2019). Oil booms are physical floating barriers employed to limit the spreading of the oil, protecting specific target areas, and aiding cleanup activities (ITOF, 2011; Ghaly & Dave, 2011; Nuka, 2014).

Table 1. Some typical hazardous properties of commercial quenching oil solutions and additives.

GHS Pictogram	H-statement	Description
	H304	May be fatal if swallowed and enters airways.
	H361	Suspected of damage fertility or unborn child.
	H373	May cause damage to organs through prolonged or repeated exposure.
	H400	Very toxic to aquatic life.
	H410	Very toxic to aquatic life with long lasting effects.

Draining of flood waters started on the afternoon of August 28 and the overall flooded area of 6900 ha was reduced to 150 ha by noon of August 29, dispatching 45 drain pump trucks in total (Tsukasa, 2019). The oil clean up started on August 29 using oil absorption mats (Tellerreport, 2019; Umitonagisa, 2019). However, the area impacted by the spill could not be drained until measures to prevent the oil reaching the Ariake sea were secured. On the morning of August 30, an area of 70 ha was still flooded (Tsukasa, 2019). Later in the afternoon, the water level was reduced employing up to 16 water drain pump trucks and activating drainage gutters once oil barriers were successfully implemented around them. As results of flood water level reduction, the roads leading to the hospital were cleared and the structure was no longer isolated (Tsukasa, 2019).

It should be noted that the area impacted by the oil was significant and required the mobilization of up to 370 people from SDF per day in addition to volunteers and factory personnel (Saga Shimbun, 2019). The cleaning activities were declared officially concluded on September 10, two weeks after the spill, with the participation of more than 640 people on that day.

A local manager of a volunteer center, run by Open Japan, one of the NGOs that removed oil from houses, said: "We wanted to start the oil removal work immediately after the flood, but we couldn't get to the site because we had to wait until the water level got down for several days after the flood, so we couldn't start the work. Difficulties of cleaning oil contaminated houses were unlike ordinary cleaning after water damage. Oil penetrates the inside of columns and walls, so even if we wash it, some oil and smell remain. Also, there were some difficulties because there were multiple residents or their relatives living in the contaminated area who were working in the factory where the oil spilled occurred. For them, it was difficult to claim damages to the factory strongly. "

In the months after the event, the company took additional measures to reduce the possibility that events of this magnitude could re-occur. Indeed, an oil fence approximately 90cm high has been installed inside the heat treatment plant surrounding the oil tanks. Moreover, permanent oil booms with a total length of about 600 meters have been installed along the east and south sides of the plant premises since these are the closest areas to the Rokkaku river (Nishinippon Shimbun, 2019). A part of the barrier is shown in Figure 5.

4.1 Preliminary damage assessment

This section is aimed at providing a preliminary evaluation of the damages brought by the oil spill. Clearly, new information is likely to be available while cleaning activities and damage assessment from the official institutions will be completed.

Figure 5. Permanent oil boom implemented in the south side of plant premises, in the closest area to Rokkaku river embankment.

(1) Residential damages

The government of Saga prefecture is releasing official information on the residential damages experienced by the population as consequence of the rainfall event of late August 2019. Damage to buildings are classified according to a severity qualitative scale spanning from the flooding of the basement only, to the complete destruction of the dwelling [68][Saga prefecture government website 2019]. Data available in the prefecture website are reported in Table 2.

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As can be noted, considering the three most severe damage categories, the majority of reported damages occurred in Takeo city and Omachi town.

In order to consider the size of each municipality and thus given an estimate of the relative impact of the event on the residential buildings of the area, the number of households for each of them has been retrieved from multiple sources (National Statistics Center, 2019; Kouhoku Town, 2019; Omachi Town Office, 2019).

Table 2. Residential damages from the rainfall event organized in six categories. From left to right damage decreases in severity (i.e. complete destruction is the most severe). Data updated to December 10th 2019. Adapted from (Source: Saga Prefecture Government, 2020).

Area	Complete destruction	Large-scale destruction	Half-destruction	Partial damage (other than flooded)	Flooded floor	Flooded foundations (underfloor)	Total
Saga-shi (佐賀市)	3	-	2	4	405	2489	2903
Karatsu-shi (唐津市)	-	1	3	2	-	23	29
Tosu-shi (鳥栖市)	-	-	-	-	1		1
Taku-shi (多久市)	-	1	29	1	40	128	199
Imari-shi (伊万里市)	-	-	-	-	2	24	26
Takeo-shi (武雄市)	2	34	705	14	200	323	1278
Ogi-shi (小城市)	2	-	7	3	63	560	635
Ureshino-shi (嬉野市)	-	-	-	-	2	9	11
Kanzaki-shi (神埼市)	-	-	-	-	-	1	1
Arita-cho (有田町)	-	-	-	-	1	-	1
Omachi-cho (大町町)	**79**	**71**	**4**	-	**17**	**130**	**301**
Kouhoku-cho (江北町)	-	-	1	-	9	167	177
Shiroishi-cho (白石町)	1	-	-	-	20	441	462
Overall	87	107	751	24	760	4295	6024

For the majority of the locations is has been possible to find data in terms of number of households updated to 2018 (National Statistics Center, 2019). For the two smallest towns (i.e., Omachi-cho and Kouhoku-cho) in Saga prefecture, data from Japan Statistics Bureau were not available, and the number of households was retrieved from information available in municipality websites (Omachi Town Office, 2019; Kouhoku Town, 2019).

Results in terms of percentage of household damaged, assuming each household corresponds to a single dwelling are reported in Figure 6. As can be noted, the highest percentages for high severity damage categories (i.e., complete and large scale destruction) are experienced in Omachi-cho, where the oil spill happened, possibly due to the additional contribution of the Natech event to the already severe impact of floodwaters.

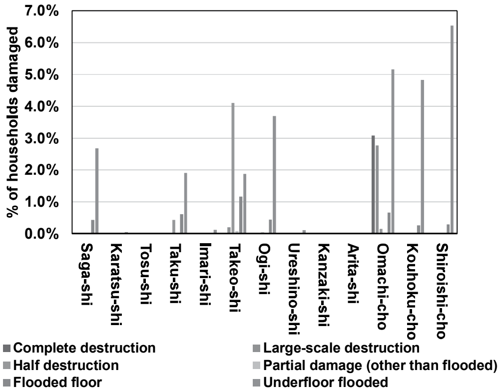

Figure 6. Percentage of households per city/town damaged by the rainfall event considering the six severity categories reported by Japanese authorities (Source: Saga Prefecture Government website).

(2) Land damages

Saga prefecture is releasing data on the extent of agricultural land damaged by the flooding event, with a specific focus on land impacted by the oil spilt from the Omachi ironworks factory (Saga prefecture, 2019). An area of 4.18E+05 m^2 (41.8 ha) is assessed to be impacted by the oil. The impacted area was mainly dedicated to rice and soy farming.

The area has been sampled, and the assessment of oil concentration is still ongoing. The definition of the proper soil remediation strategy and the assessment of its cost are strongly dependent on the oil concentration which is found in the ground samples. A preliminary evaluation of cost directly connected to agricultural soil remediation activity is performed considering an analogous case of oil spill happened in Ryuo-cho in 2018 (Lake Biwa Environment Department, 2018). In that case, Japanese authorities implemented two different strategies following a threshold-based approach on the measured oil concentration in mg/kg. In case the oil concentration for an area is below a previously defined value of 100 mg/kg, the strategy which is followed is lime spreading in the soil without any additional measure. In case the threshold value is surpassed, the first layer of soil is replaced. In the case of Ryuo-cho, a layer 15cm thick was removed. The unitary cost of the two remediation strategies can be estimated directly from the information available in the governmental report on this past accident (Lake Biwa Environment Department, 2018).

Considering the impacted area, the soil remediation cost may range between 1.2E+06 JPY and 7.82E+08 JPY, according to the strategy that will be followed depending on the results of soil sampling.

According to recent news, the main strategy that will be implemented is lime spraying in the majority of surveyed sites, indicating that the oil concentration in soil samples is generally low. However, detailed data on the extent of the surface is not available to date (Economie FGG, 2020).

Table 3. Soil remediation strategies adopted in Ryuo-cho oil spill (2018). From (Lake Biwa Environment Department, 2018).

Remediation strategy	Implementation area (Ryou-cho, 2018) [m2]	Implementation cost (Ryou-cho, 2018) [106 JPY]	Estimate unitary cost [(106JPY)/m2]
Lime spreading	4.18E+05	1.20	2.87E-06
Soil replacement	1.0E+03	1.87	1.87E-03

5. Discussion

The case study presented throughout the paper offers a series of lessons on Natechs caused by flooding. First of all, it should be noted that the process employed by the facility to perform the thermal treatment is inherently unsafe when applied in areas prone to flood hazard. It is clear that the presence of significant quantities of a hazardous substance accessible from the ground level is a poor design solution considering the possibility of water entering the tanks. Moreover, since the oil is lighter than floodwater, it may easily float out of the containment vessels if the amount of water entering is sufficient to cause overflow. The company declared that the water level reached during the flooding of August 2019 was unexpected, and may have exceeded the design level of protection measures adopted after the previous oils spill incident. Given the possibility that extreme weather events such as the 2019 event, may reoccur, the company should evaluate either the implementation of different technology for thermal treatment, or the relocation of the plant to an area where the flood hazard is lower.

The company should consider the application of screening techniques for evaluation of barriers for accident prevention and mitigation. For instance, a Layer of Protection Analysis (LOPA) approach may be followed, defining a set of countermeasures, where each of them is independent and capable of preventing scenarios like the oil spill of August 2019 (Center of Chemical Process Safety, 2001).

It should also be noted that research on the potential for Natech accidents occurring in the metal processing industry is lacking. Indeed, this industrial sector was included in one research paper focused on the development of qualitative damage scales due to flooding only by Krausmann & Mushtaq (2008). It is worth noting that this category of industries in Japan have been involved in two other Natech accidents in 2018 (Environmental Agriculture Administration Standing Committee., 2018; Araki *et al.*, 2020), in addition to the case described in this work. This clearly points out that research efforts should be devoted to the development of strategies for reducing the risk of Natech accidents involving metal processing industries.

At the municipality level, the oil spill scenario should be considered when evaluating both emergency planning operations and damage assessment. Indeed, the area impacted by the substance sheen was the last one to be drained, possibly increasing the severity of the damages brought by floodwaters (e.g., dwelling foundations submerged for a long time). The presence of oil required also the implementation of specific measures such as oil booms and absorption mats, that may not be required in case of flooding scenarios not triggering hazardous substance releases. Moreover, it is clear the land use planning of the area did not consider the possibility of oil spills concurrent with flood events despite the fact that accidents have already occurred. As an example, the hospital was located in an area exposed to severe flood hazard (see Figure 2), and possibly for this reason the elevation of the soil where the structure lays is higher than the surrounding farmland. During the field inspection on the area, from the flood signs left on the external walls of the building it was clear that the water level reached about 30cm in the entrance. Nevertheless, the presence of the oil lead to isolation of the structure, a scenario that was apparently not considered. Therefore, the municipality should evaluate relocation of the hospital, since it is a critical infrastructure and there is the possibility that compound disasters like this hamper severely its functionality.

6. Conclusions

In this work a recent Natech accident is presented. The accident involved the release of a large quantity of metal quenching oil as a consequence of massive flooding brought by severe downpours that hit southwest Japan in late August 2019. The oil spill slowed down emergency intervention and site clean-up activities, posing an additional burden on emergency teams. The factory involved in the oil spill had already experienced an analogous event in 1990, and the barriers designed after that event were reportedly not suitable to deal with the extreme rainfall the lead to the latest accident. The projection of climate change impacts in Japan, pose additional concerns on how extreme weather events may increase in severity and frequency in the future, enhancing the risk to the communities living around the ironworks plant are exposed, and other hazardous installations. The present work is not intended to be concluded, since damage assessment is still ongoing. Nevertheless, the case study presented should raise awareness on the severity of possible Natech accidents involving industrial sectors that are usually overlooked by regulatory frameworks and the scientific literature on the topic.

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